

CHAPTER 6

RELIABILITY IMPROVEMENT

6-1. Data collection

In chapters 3 and 4, the importance and use of data during design was discussed. Collecting and analyzing data from development testing is an important part of the process of designing for and improving reliability. In chapter 5, we saw that the need for data does not end with the completion of design and development but is an important part of the overall quality control program. Data collection is also important during the life of a system.

a. *Importance of operational data use to the manufacturer.* For systems having some form of warranty, the manufacturer can use return data, to assess the economic viability of making changes to the design or manufacturing processes. Table 6-1 lists some of the ways in which the manufacturer can use data collected during the operational life of the system. Even when it is not economically advantageous to reduce the warranty claims for the current system, the data may show where changes should be made in the next system. Although it is relatively simple for the manufacturer to collect data during the warranty period, the effort becomes difficult and often impossible after the warranty expires. Often, it is only feasible to continue data collection when the manufacturer is providing maintenance or other logistics support over a system's life.

Table 6-1. Manufacturer's use of operational data

Type of Data	Use
Actual number of warranty returns versus expected number	Determine if potential reliability, operator, or maintenance problems exist, forecast actual warranty costs
Customer complaints	Qualitatively determine level of system performance
Repair data*	Determine nature of failures, frequency of repair
Failure analysis data*	Determine failure causes, refine or develop design requirements (standard practices), develop design, part selection, source, or other changes

*When the manufacturer is given access to such data by the customer or is providing the maintenance.

b. *Importance of operational data use to the customer.* The user is always interested in evaluating the performance of a system and in measuring the resources needed to operate and support the system. If the manufacturer or a third-party source is providing the logistics support (perhaps even operating the system), then the applicable service contract should include the requirement to collect data and use that data in managing the services being provided. The user has some of the same objectives as a manufacturer in collecting operating data but has some additional ones. Some of the ways in which the user can use data collected during the operational life of the system are listed in table 6-2.

Table 6-2. User's use of operational data

Type of Data	Use
Actual number of warranty returns versus expected number	Forecast impact of delivery schedules. Qualitatively determine level of system performance.
Repair data*	Determine nature of failures, frequency of repair.
Failure analysis data*	Determine failure causes, refine or develop design requirements (standard practices), develop design, part selection, source, or other changes.

*When the user is providing the maintenance.

6-2. Conduct trending

Once a system is fielded, it is important to collect performance data during its operational life. Such data can be used for a variety of purposes including detecting negative trends in reliability in sufficient time to take prompt corrective action. Although positive trends can occur, they are the exception – system reliability usually degrades over time.

a. *System failure behavior.* During their useful life, most systems tend to behave as if the times between system failures are exponentially distributed. This behavior results because a system is made up of many different types of parts and assemblies, each having its own failure characteristics. Due to the mix of failure modes and varying underlying failure distributions, a system has a constant rate of failure (and a constant mean time between failure, MTBF), unless the reliability is improving or degrading. The reliability improves when some action is being taken to decrease the number of failure per unit time. These actions can include design changes, improved maintenance training, and changes in operating procedures. Degradation of system reliability can occur for a variety of reasons, some of which are shown in table 6-3.

Table 6-3. Reasons why system reliability degrades over time

Reason	Discussion
Change in operating concept	If system is used in a manner different from that originally allowed for in the design, new failure modes can occur and the overall frequency of failures can increase. In such cases, corrective actions can be expensive or impractical. If the new operating concept is essential, decreased reliability may have to be accepted.
Change in operating environment	If a system is used in an environment different from that originally allowed for in the design, new failure modes can occur and the overall frequency of failures can increase. In such cases, corrective actions can be expensive or impractical. If the new operating concept is essential, decreased reliability may have to be accepted.
Inadequate training	If operating or maintenance training is inadequate, the number of failures induced by improper operation or maintenance usually increases. The corrective action is to improve the training.
Wearout	As systems age, the number of failures per unit time of parts having wearout characteristics, primarily mechanical parts, will increase. A preventive maintenance program to replace or overhaul such parts will prevent wearout from becoming a problem. Ideally, the preventive maintenance program is based on the reliability characteristics of the parts (i.e., a reliability-centered maintenance program).
Change in supplier	If a supplier chooses to stop manufacturing a part or material, goes out of business, or no longer maintains the necessary levels of quality, an alternate source of supply is needed. If reliability is not a major consideration in selecting the new supplier, system reliability may degrade.
Poor configuration control	Over a system's life, there is the temptation to reduce costs by substituting lower-priced parts and materials for those originally specified by the designer. Although the purchase price may be lower, life cycle costs will increase and the mission will suffer if the "suitable subs" do not have the necessary reliability characteristics. Strong configuration management and a change control process that addresses all factors, including reliability, are essential throughout the life of the system.
Manufacturing problems	Although the manufacturing processes may have been qualified and statistical process implemented at the start of production, changes can occur during the production line that degrade reliability. This possibility increases as the length of the production run increases. Constant quality control is essential.

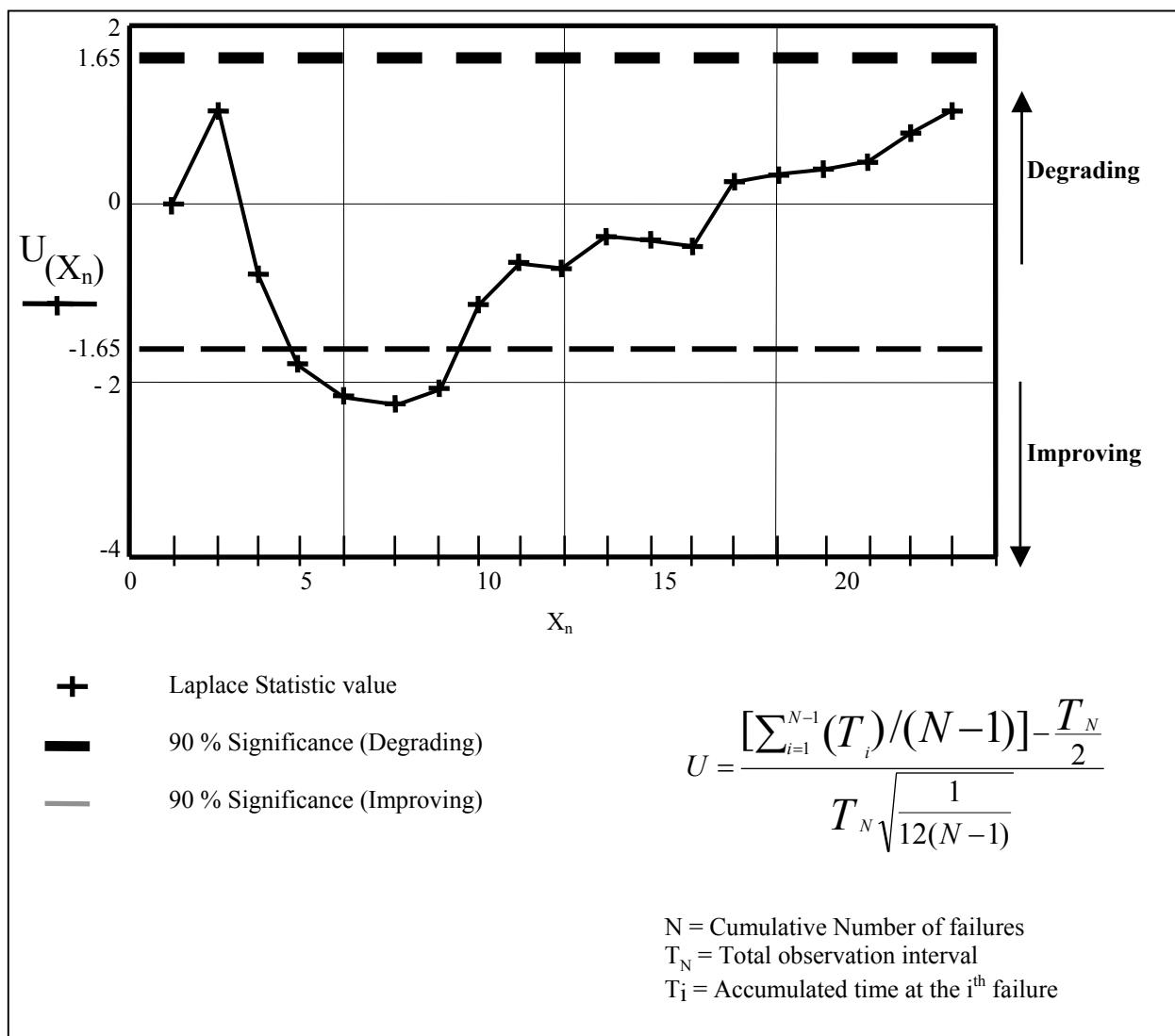
b. *Detecting trends in system reliability.* Although systems do tend to exhibit a constant MTBF during their useful lives, some statistical variation in the MTBF is to be expected. Whether the MTBF of a single system or a population of systems is being measured, the measured value will fluctuate. Some of this fluctuation is the result of statistical variation. Some fluctuation may result from operating at different times of the year or in different operating locations. For example, hydraulic seals may leak more during cold weather (winter) or when the temperatures are widely varying from day to day (possible in spring or fall). It is important to distinguish between such "normal" variation and a genuine negative trend. One tool for making this distinction is the Laplace statistic.

(1) The Laplace statistic, U, came from work done by the French mathematician Pierre-Simon Laplace. In 1778, he showed that U will be normally distributed with a mean of 0 and standard deviation of 1 when no trend is evident from the data with a given level of confidence. In the case of times to failure, if U is normally distributed with a mean of 0 and standard deviation of 1, the times between failures are exponentially distributed. Otherwise, a negative or positive trend exists. The presence or absence of a trend must be stated with a given level of confidence. That is, we cannot be 100% certain that a trend does or does not exist. Instead, we must accept some risk that we are wrong (i.e., we state there is a trend and there is not or we state that there is no trend and there really is).

(2) The following example illustrates how the Laplace statistic can be used to track system reliability and detect a trend. Suppose we have the failure data shown in table 6-4 for an electrical generation system. For each data point, the U statistic is calculated using the equation shown in figure 6-1 for failure truncation observations (i.e., the observations ended after a pre-determined number of failures) and plotted. (Note: if the observations ceased after a given time, a different equation would be used.) The values are shown in table 6-5. The control limits are based on the desired level of confidence. In this example, we used a confidence level of 90%. As long as the plotted values of U remain within the control limits, we can state with 90% confidence that there is no trend.

Table 6-4. Failure data for example

Failure No.	Hrs. at Failure	Failure No.	Hrs. at Failure	Failure No.	Hrs. at Failure
1	296	8	14971	15	22076
2	348	9	15056	16	23159
3	1292	10	17415	17	24589
4	2923	11	17473	18	24679
5	6405	12	19686	19	24764
	6	10746	13	19692	
	7	14934	14	21058	

Figure 6-1. Equation for U and plot of U values at 90% confidence for example.Table 6-5. Table of calculated values of U for example

Failure Number	U	Failure Number	U
1	0*	11	-0.18676
2	1.214426	12	-0.3403
3	-1.22854	13	0.172303
4	-1.67533	14	0.198925
5	-2.15012	15	0.325564
6	-2.24911	16	0.412416
7	-2.15835	17	0.38101
8	-1.35159	18	0.760795
9	-0.6759	19	1.118446
10	-0.75564		

*It is impossible to determine a trend with one data point, so U is 0.

(3) Even when the plotted values of U do not fall outside of the control limits, rules of thumb can be used to determine if a potential problem is indicated by the data. These rules of thumb are shown in table 6-6.

Table 6-6. Three possible signs of a problem when no points are outside of the upper control limit

Sign	Example	Discussion
7 consecutive points monotonically going in the "wrong" direction (toward the upper limit)	<p>A control chart with a horizontal center line, an upper control limit (UCL) dashed line above it, and a lower control limit (LCL) dashed line below it. A series of 14 data points are plotted as solid circles connected by a line. The points start below the center line, fluctuate, and then trend upwards, ending near the UCL.</p>	<p>Statistical variation makes it highly unlikely that any of these three signs occur due to chance. In other words, it is likely that the sign occurs due to:</p> <ul style="list-style-type: none"> ▪ A real degradation in reliability ▪ Irregularities in data reporting ▪ Unusual or improper actions by operators or maintainers ▪ Other changes
14 points alternating up and down	<p>A control chart with a horizontal center line, an upper control limit (UCL) dashed line above it, and a lower control limit (LCL) dashed line below it. A series of 14 data points are plotted as solid circles connected by a line. The points alternate between being above the UCL and below the LCL, creating a sawtooth pattern.</p>	<p>Whenever any of these signs are observed or when the plot goes above the UCL, additional investigation should be conducted to determine the underlying root cause.</p>
10 consecutive points above the center line	<p>A control chart with a horizontal center line, an upper control limit (UCL) dashed line above it, and a lower control limit (LCL) dashed line below it. A series of 14 data points are plotted as solid circles connected by a line. The points start below the center line, fluctuate, and then trend upwards, ending near the UCL. This is a subset of the first sign where the trend continues for 10 points.</p>	

6-3. Identify needed corrective actions

When trending, field returns, and other user complaints indicate a problem in system performance, analysis is required to determine the root cause of the problem. As suggested earlier, the root causes may be the way the system is being maintained or operated, problems in the manufacturing process, or premature wearout. It is critical that the true cause be determined. Obviously changing the design is inappropriate if the true cause of the problem is an increase in induced failures due to inadequate training of maintenance personnel. Table 6-7 lists some of the potential causes of reliability degradation and the ways in which that degradation might be addressed. Corrective actions are taken only if safety is concerned or when the benefits outweigh the costs of implementing the corrective action.

Table 6-7. Causes of reliability degradation and potential corrective actions

Cause	Potential Corrective Actions
Premature wearout	Parts may have been inappropriately selected or applied; select higher reliability parts to replace the offending parts; evaluate effectiveness and frequency of preventive maintenance; select different supplier that provides higher reliability parts.
Unforeseen failure modes	Initial description of operating environment and stresses may have been incomplete or inaccurate; review original analyses and conduct additional analyses to determine if any design changes or changes in parts application or indicated.
Higher frequency of failures than forecasted	Initial description of operating environment and stresses may have been incomplete or inaccurate; review original analyses and conduct additional analyses to determine if any design changes or changes in parts application or indicated.
Inadequate training	Training may not have been developed or implemented properly; ensure training is effective and accurate; ensure all personnel, operational and support, receive necessary training before operating or working on the system; ensure all personnel stay up-to-date on system operation and maintenance.
Improper operation	Operating procedures may not have been developed properly, are out of date, or are not being followed; ensure procedures are accurate and up-to-date and all operators are following procedures.
Improper maintenance	Maintenance procedures may not have been developed properly, are out of date, or are not being followed; ensure procedures are accurate and up-to-date and all maintenance personnel are following procedures.